Simplified Stowage Systems for Spaceflight

A Human Centered Approach Toward Improving Habitability on the International Space Station

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Historical Perspective

Skylab IVA

Skylab general description

Launched in 1973, the 75-ton space station was fabricated by modifying the empty third stage of a Saturn IV-B rocket, creating a 50-foot long, 20-foot wide cylindrical work area. Despite its cavernous interior, stowage and cargo management on Skylab was problematic. The station's open cylindrical architecture and indiscriminate use of floors, ceilings, and walls for attaching equipment made locating necessary items difficult without formal inventory management and location coding systems.

Mir IVA

Mir general description

In operation from 1986 till 2001, the Mir space station grew over its lifetime with the delivery of additional modules. Despite its increasingly large working volume, the station fell victim to a net flux of items delivered to the station with no effective means of returning equipment to the Earth until the Shuttle-Mir program in 1995, ultimately resulting in a cramped, cluttered interior.

Skylab lessons learned

- Use an inventory management system to track the location of equipment
- Develop an intuitive location coding system such as locker numbering and labeling system
- Implement a trash management plan
- Provide temporary stowage capability
- Develop an on-orbit stowage transfer plan to minimize relocation of previously stowed items
- Secure individual items within lockers

Mir lessons learned

- Minimize nonstandard stowage impacts to intra-module navigation
- Prevent stowage from occluding critical equipment and controls such as control panels, fire extinguishers, and oxygen masks
- Prevent stowage from impacting crew quarters and other crew spaces
- Prevent locating and rearranging items from creating unscheduled timeline impacts
- Return unused items and equipment
- Provide location coding system that accounts for nonstandard stowage
- Provide temporary stowage and staging areas
- Maintain a trash management plan
- Minimize the usage of packing foam
- Prevent over supply of some unnecessary items

Lessons-based improvements planned for ISS

- Creation of an intuitive location coding system to identify module, rack, and locker positions
- Development of operational constraints to maintain minimal translation path through the modules
- Development of operational constraints that prevent stowage from blocking critical equipment and controls such as exercise equipment and fire ports
- Crew sleeping quarters protected from stowage
- Development of an inventory management system
- Creation of a trash management plan
- Improved management of packing foam and returning foam to Earth on the logistics module and Shuttle

Illustrations above and above right from: *Island in the Sky: Building the International Space Station;* Piers Bizony; London: Aurum Press Limited, 1996

Illustration at right from: *Living in Space: From Science Fiction to the International Space Station;* Giovanni Caprara; Buffalo, N.Y.: Firefly Books (U.S., Inc.), 2000

Artist's concepts of ISS interior

A common public perspective on the future of spaceflight prior to operation of the International Space Station

"Clean Cabin: In Comparison to Skylab and Mir, the International Space Station will provide very orderly working areas, with no harsh surfaces or unwelcome clutter."

– Island in the Sky: Building the International Space Station; Piers Bizony; London: Aurum Press Limited, 1996

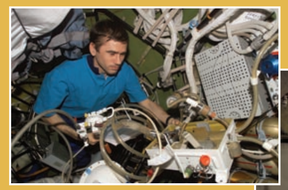
Problem: Despite efforts to incorporate lessons learned from the Skylab and Mir programs, the ISS stowage integration plan did not result in the uncluttered orderly environment envisioned by NASA planners

ISS Today

Current ISS stowage issues

Key issues

- Stowage impacts to productivity
  - It is estimated that crewmembers each lose 0.75 hour per day retrieving and rearranging stowed items
- Stowage impacts to habitability
  - Crowded aisle ways impact crew translation and lighting, and leave otherwise spacious modules feeling dark, cluttered, and congested
- Stowage impacts to safety
  - Excess stowage potentially blocks critical equipment and makes emergency equipment difficult to access



Goal: Develop concepts for simplified stowage systems that will optimize the use of stowage spaces while increasing habitability and productivity of on-orbit crew time

Key causes

- More items are brought up than are returned
  - Shuttle arrives full and leaves less than full
  - Net flux of items into the Station
- Pre-positioning of hardware
  - Large EVA equipment such as bearing, motor and roll ring module
  - Orbital spares
  - Food for future expeditions
- Coordinating stowage integration with Russian program is time consuming, and can impact real-time operations
  - Difficult to certify U.S. items for disposal of items on Russian Progress
  - Difficult to approve U.S. items for stowage in Russian Service Module and Cargo Block
- Over supply of certain items
  - Clothing
  - Napkins
  - Towels

Roadmap to Improvement

Review debriefs and lessons learned

- Crew needs to relocate stowage to access equipment
- Timeline does not account for time to acquire and put away equipment
- Nonstandard stowage blocks lighting in Node 1 module
- Inventory management system is only as good as its database
  - Disciplined crew utilization of IMS is required
- Crew needs advanced permission to throw away items on Russian Progress vehicle
- Stowage does not fit standard stowage lockers
  - Standard stowage bags
  - Food containers

Investigate tactical integration and planning

- Manifest
  - Prioritization of cargo
  - Requirements for contingency items
- Launch
  - Limits to mass and volume
  - Vehicle integration requirements
- Stowage
  - Planning methodologies
  - Utilization of dedicated stowage volumes
  - Identification of new stowage locations
- Use
  - Challenges to execution of tactical plan
  - Task-specific stowage considerations
- Downmass
  - Limits to mass and volume
  - Vehicle integration limitations
  - Timelining limitations

Identify design requirements

- Affordability
- Intuitive operation
- Integration with existing hardware
- Materials
- Human factors
- Launch loads
- Secondary implicit requirements
- Others?

Identify root causes

- Net flux of items to Station
- U.S.-Russian coordination challenges
- Overly restrictive requirements and constraints
- Inability of ground to plan for off-nominal impacts to timeline
- Others?

Research-relevant technologies

- Wireless tracking technology
- Advanced database systems
- State-of-the-art packaging
- Others?

Evaluate analogs

- Advanced archives and warehouse facilities
- Submarines
- Arctic bases and other remote sites
- Others?

Investigate potential design innovations

- Automated Inventory Management System?
  - Wireless digital tracking
  - Crew voice recording of location for later download
- New crew transfer bags?
  - Improved labeling, color coding, and sizing of existing stowge locations
  - Improved packing foam
- Collapsible stowage racks?
- Reconfigurable web-style stowage restraints?
- Outfitting logistics module for greater return capacity?
- Outfitting logistics module to act as a permanent "stowage module" on orbit?
- Others?

Investigate potential process improvements

- Limit manifest of unneeded items?
  - Establish "deficit" limits to prevent stowage creep on Station
  - Balance upmass and downmass of cargo
- Improved coordination between U.S. and Russian Programs?
  - Bulk certification of items for stowage in Russian Segment or return in Progress
  - Limit manifest of unneeded or overstocked items
- Identify unneeded items on orbit for down manifest?
  - Return broken hardware, completed experiments, overstocked items
- Improve communication of item locations to Inventory Management System
- Improve "Pantry Style" stowage?
  - Put similar items together and place items near where they will be used
- Improve timelining of crew tasks?
  - Include time to reposition stowage, locate lost items, and put items away at the end of tasks
- Others?

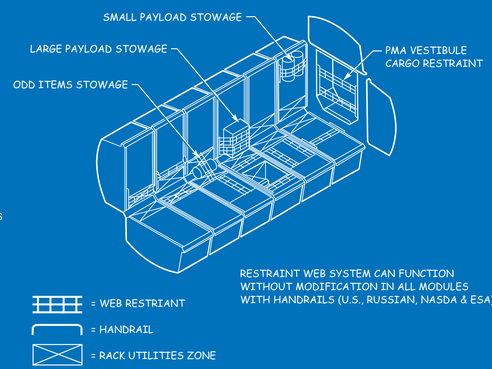
Design

- Conceptual sketches
- CAD models and integration analysis
- Scale mockup development
- Full-scale mockup development
- Task analysis
- Usability evaluation
- Crew evaluation

Perform feasibility assessment

- Internal evaluation of concepts vs. requirements
- Identification of design challenges
- Identification of implementation challenges
- First-order cost assessment
- Selection of final recommendations

FABRIC WEB PAYLOAD RESTRAINT CONCEPT
PATRICK SINNOTT, JAN 2003



RESTRAINT WEB SYSTEM CAN FUNCTION WITHOUT MODIFICATION IN ALL MODULES WITH HANDRAILS (U.S., RUSSIAN, NASDA & ESA).

Analysis report

- Review of stowage-related debrief concerns
- Summary of recurring issues
- Analysis of stowage manifest and tactical planning processes
- Summary of root causes
- Review of analysis methodologies
- Key process improvement recommendations
- Potential design innovations
- Forward plan

Final design recommendations

- Three to four system prototypes
- Results of usability analyses
- Strengths and weaknesses report
- Forward plan

Final process recommendations

- Five to six key process improvements
- Results of feasibility assessment
- Strengths and weaknesses report
- Implementation plan